APPENDIX 5-13

MODEL SELECTION AND DESIGN CONDITIONS FOR WAVE RUN-UP MODEL

BLACK & VEATCH

TECHNICAL MEMORANDUM

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Model Selection and Design Conditions for Wave Run-Up Model

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To: Distribution

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1. OBJECTIVE

The overall objectives of the Wave Run-up Model are as follows:

- To determine the amount of freeboard required to prevent over-topping of the reservoir embankment during high wind and rain conditions,
- To determine the effectiveness of internal breakwaters in decreasing wave run-up.

This memorandum summarizes the first tasks completed in developing the wave run-up model and includes a discussion of obtaining existing data, model review and selection, and the design conditions to be used in the modeling for the wave run-up.

DATA COLLECTION

The data to be used in the Wave Run-Up Model include meteorological data on winds, rainfall, and barometric pressure, topographic data and the design parameters for the reservoir. The primary sources of data are the National Weather Service (NWS) and existing United States Geological Service (USGS) topographic maps. Meteorological data for the period of record were obtained from the National Climatic Data Center (NCDC) for four inland stations. Additional data were obtained from the National Oceanic and Atmospheric Administration's (NOAA) Tropical Prediction Center. Wind data, both direction and speed were sought around the EAA proposed reservoir. The South Florida Water Management District (SFWMD) online database was reviewed to determine if its data were appropriate for the Wave Run-up Model. It appeared that the SFWMD site stores only daily average values for wind speed and other meteorological data. Furthermore, there were very few stations which had a combination of both direction and speed measurements. Since the Wave Run-Up model needs a finer resolution than daily average values for wind speed and direction and because few SFWMD stations had appropriate wind parameters, other data sources were used.

The NCDC has weather stations all across the continental United States. Stations designated as "first order" weather stations are locations where data are recorded by trained personnel and whose meteorological instruments are constantly maintained. These weather stations are known to have the most robust and reliable meteorological data. Four first order stations around the proposed EAA reservoir were located. Hourly digital wind data (both direction and speed) along with other meteorological parameters are available for these stations in excess of 30 years. Also, the data are current and therefore, include records of the major hurricanes that occurred in 2004. The stations were selected based on proximity to the EAA reservoir site and parameters measured at the sites. The first order stations that were selected are listed below:

- Orlando International Airport: WBAN 12815FL
- Fort Meyers Page Field: WBAN 12835FL
- West Palm Beach: WBAN 12844FL

- Avon Park Gun Range: WBAN 12804FL

The hourly data was received from the NCDC on December 23, 2004 and are currently under review. Additional data requests will be made, if needed. Data specifically on the hurricanes have been obtained from the Tropical Prediction Center.

The rainfall data to be used in the Wave Run-up Model is the same data set to be used for the water balance model. Rainfall data have been obtained from the District and is the same set used for previous modeling conducted using the SFWMD Model (2 x 2 model).

Information on the likely size of the reservoir is currently being refined. Areas needed for buffers, easements and seepage channels have been superimposed on the property boundaries to obtain a better estimate of distances, areas, and volumes for the reservoir.

2. MODEL SELECTION

Based on our understanding that the design should meet USACE requirements, it was anticipated that the USACE model ACES (Automated Coastal Engineering System) would be used to calculate freeboard requirements. However, it was also recognized that other available models should be further reviewed prior to beginning the wave run-up analysis. The models reviewed included the following:

- Automated Coastal Engineering System (ACES)
- Sea, Lake, and Overland Surges from Hurricanes (SLOSH)
- Coastal Hazard Analysis Modeling program (CHAMP)
- Steady State Spectral Wave Model (STWAVE)
- Mike 21
- Simulated Waves Near Shore (SWAN)
- Advanced Circulation Model for Oceanic, Coastal and Estuarine Waters (ADCIRC)
- Wind Set-up models

The models were evaluated to determine their specific features, such as wave generation, wind set-up, breaking waves, and evaluation of internal structures. In addition, their applicability for both shallow and deep water waves, availability, and effectiveness were investigated.

2.1 Automated Coastal Engineering System (ACES)

Designed by the United States Army Corp Engineers ACES is a system of microcomputer programs used in coastal engineering design and planning. It is part of the Coastal Engineering Design and Analysis System (CEDAS). The program meets FEMA standards as well as USACE standards. This model can calculate wave run up and allows for wind set-up to be included in the calculations. This can be added to peak wave heights in order to calculate freeboard design. The program is available through the USACE and runs well for both shallow and deep water waves.

ACES is simpler than some of the other models evaluated because it does not account for variables such as complex bathymetry, dissipation of energy, diffraction or refraction. However, the program has multiple functions including calculating wave height, wind set-up and wave run-up and can be used to simulate the effects of internal structures.

2.2 Sea, Lake and Overland Surges From Hurricanes (SLOSH)

The SLOSH program was developed by the National Weather Service and is currently used by the National Oceanic and Atmospheric Administration (NOAA) to set evacuation zones for incoming hurricanes. This program is primarily used to calculate the extent of flooding in areas as a result of hurricane induced storm surges. The program relies on knowing the barometric pressure of the storm, its location and path, the speed of the hurricane and land features such as underwater sills, channels and rivers as well as the storm's size. This model is usually accurate within plus or minus 20 percent. The hurricane's point of landfall and path are so critical to showing which areas will be flooded that if the forecast is inaccurate the model will be also.

The model does not calculate wave run-up but allows it to be added to the model later to help calculate freeboard requirements. Wind set-up is also not calculated and in fact, wind speeds are not incorporated into the model. The program predicts wind speeds of the storm using the pressure at the center and the hurricane's size. The model does not account for rainfall, wind driven waves, river flow or wind set-up. The program is also not readably available to the public and a special request to NOAA would have to be made to gain access to the model.

2.3 Coastal Hazard Analysis Modeling Program (CHAMP)

The Federal Emergency Management Agency (FEMA) designed this model. The primary use of this model is to establish coastal hazard assessments of fine-scale wave phenomena associated with hurricane storm surges or northeaster flooding effects. The methodologies primarily used are storm-induced erosion treatments, wave height analyses, and wave run-up analyses. The program can account for wave set-up but not for wind set-up. It works well for both deep and shallow water. Wind speed is not an input but storm type and station readings allow the model to take wind into account. It does this with hurricane force winds simulated depending on the storm rating given. The program has multiple parts: Storm Erosion Treatment, Wave Height Analysis, Wave Run-up Model, Storm Surge Flood, and Wave Overtopping. It is available for download and has various tutorials online.

2.4 Steady State Spectral Wave Model (STWAVE)

Coastal and Hydraulic Laboratories designed this model. It assumes steady state waves and winds. The model performs a very detailed analysis of waves and how they react to other waves and shores. The model studies multiple facets of waves all at once not like many other programs that take one at a time. The model is applicable for shallow to moderately deep water but not very accurate for bodies of water with depths greater than 40 ft. It includes many different characteristics such as white capping, wave transformation due to refraction, diffraction, and shoaling.

The model's primary input is wave energy heading into grid. It has the capability to simulate a great variety of wave phenomena, such as depth induced wave refraction, and shoaling, current induced refraction and shoaling, depth and steepness induced wave breaking, diffraction, wind-wave growth, wave-wave interaction and white capping that redistribute and dissipate energy in growing wave fields. The model assumes a mild sloped bottom, negligible wave reflection, linear refraction shoaling, and depth uniform current. The input required is bathymetry, incident wave spectra, wind and water levels, and current fields. The output given by the model is field wave height, wave field period and duration, and fields of break incidents. The model does not however calculate wave run-up or wind set-up. The model is available online.

2.5 Mike 21

Mike 21 was developed by the Danish Hydraulic Institute (DHI) as a coastal water design and planning model. It has multiple applications varying from coastal design to water treatment. It can calculate wave height, accounting for both diffraction and shoaling; however, it ignores wave breaking and refraction. The model includes coastal hydraulics, environmental hydraulics, sediment process and wave process. Some calculations performed include significant wave height, peak wave period, mean wave period, peak wave direction, wave frequency, wave energy spectra, and wave run-up. The wave run-up calculation is done by Boussinesq short wave model. No wind set-up calculations can be done on the model. The model works well for shallow and deep water.

2.6 Simulated Waves Near Shore (SWAN)

SWAN is a third generation numerical model developed by Delft Hydraulics for the estimation of wave parameters in coastal areas, lakes and estuaries. The program uses bathymetric, wind and current conditions as input. It includes wave dissipation through bottom friction, white capping, and depth induced wave breaking, as well as energy redistribution by non-linear wave-wave interactions. It can calculate wave height and overtopping easily. It does allow wave set-up to be considered for calculations, but does not calculate wave run-up or wind set-up. This program is available online for downloading. Due to the model's size and complexity it requires a significant amount of computer power and time.

2.7 Advanced Circulation Model for Oceanic, Coastal and Estuarine Waters (ADCIRC)

The University of North Carolina and Notre Dame University developed this model. It addresses free surface circular and transportation problems in two (2) or three (3) dimensions. Applications include modeling tide and wind driven circulation in coastal waters. This is usually used to forecast hurricane surge flooding as well as dredging feasibility and larval transport studies. Special features of the model are wetting and drying, overflow and through flow barriers, bridge piers, and wave radiation stress. The output most appropriate to this project is wave height and wave run up. The model can simulate wave induced shoaling, and refraction. This model is also available online and is appropriate for both deep and shallow water waves.

2.8 Wind Set-up Models

Wind set-up can be an important factor in determining freeboard requirements. For those models that do not include wind set-up, the effects should be calculated separately and added to the wave height results. Three methods to calculate wind set-up are discussed in this section, the Zeider Zee formula, the Bretschneider Model and the Sibul model.

The Zeider Zee formula is an empirical relationship originally derived for deep, long, narrow bodies of water. The EAA reservoirs will be relatively wide and short and the Zeider Zee formula would overestimate the wind set-up for this shape of reservoir.

The Bretschneider model is a numerical model derived under steady state wind conditions. The model is based on surface and bottom shear stresses as well as conservation of mass. With a combination of wind shear stress and bed shear stress, a wind drag coefficient is derived. The coefficient is impacted by wind speeds, wave steepness and salinity. The coefficient is not a true constant and therefore varies depending on conditions. The model is not as specialized as the Zeider Zee so it has more variables and is more general in its approach.

The Sibul model is a numerical model derived from various laboratory and field investigations. The formula is based on wind sheer stress, drag coefficient, density of air and wind speed. This formula uses a derived coefficient for the wind shear stress and uses that for the calculation of the vertical set-up. With this model the slope of the waves can be attained using a derivation of the set-up equation.

2.9 Recommendation

The two models that are best suited for this project are the ACES model and the STWAVE model. The STWAVE model has some features not incorporated in the ACES model such as wave energy dissipation, linear wave refraction and shoaling. The STWAVE model could be used only to calculate wave heights; wind set-up and wave run-up would have to be calculated separately.

The ACES model is a computerized version of methods and equations developed and used by the Corps over many years. It is capable of simulating the important features needed to calculate the freeboard requirements including wave height, wind set-up and wave run-up. It is the only one of the models reviewed that calculates wave run-up. The ACES model would be the best overall model for use in this project.

3. DESIGN CONDITIONS

The design conditions that will be modeled include variations in both weather and operation conditions and will be based on the hazard classification for the structure, as well as FEMA and USACE guidelines to meet dam safety guidelines. Weather conditions will include three (3) different combinations of winds and rainfall amounts. Operational conditions will include the reservoir at a 12-foot depth and two other depths. Design alternatives will include two (2) different internal slope conditions.

Weather conditions to be evaluated with the wave run-up model include three combinations of wind and rainfall amounts. The first condition will represent a category one hurricane with normal rainfall associated with a hurricane of that magnitude. The second condition will represent a hurricane event in combination with the Probable Maximum Precipitation (PMP). The third condition will represent a hurricane with very strong winds (category 3 or 4) and rainfall normally associated with that type of hurricane. The exact wind velocities associated with these events will be determined by the wind analysis task and will be presented in Work Order 3 Technical Memorandum #3 to be submitted to the District on January 14, 2005. The wind velocities selected will be based on historical wind data obtained from the NCDC and on winds recorded for the 2004 hurricanes that affected south and central Florida.

The PMP will be calculated during a task included in Work Order 5 and will not be completed before the wave run-up model runs are made. However, an initial estimate of the PMP will be made and used in the modeling. Work Order 5 includes a task to make refinements to the wave run-up calculations. When the final PMP value is defined, the wave run-up model will be rerun to determine the freeboard requirements for this condition. The other rainfall conditions will be based on average rainfalls associated with the defined hurricane events.

Operational conditions will include the reservoir at a depth of 12 feet and two (2) other depths. It is recommended that the two other depths be sufficient to achieve specific storage volumes up to 240,000 ac-ft. Because the footprint of the reservoir is not yet finalized, the depths are not yet known. Two internal slopes will also be evaluated including a 3 to 1 slope and one other to be defined by the geotechnical engineers working on the project. Finally, three (3) different internal breakwater structures arrangements will be evaluated. The types of internal structures to be evaluated will be defined by the embankment designers.

4. SUMMARY

This memorandum summarizes the first tasks completed in developing the Wave Run-up Model and includes a discussion of existing data, model selection, and the design conditions to be simulated. Wind data have been obtained from NCDC and the NOAA Tropical Prediction Center. Rainfall data have been obtained from the District.

After reviewing additional models that could be used to determine freeboard requirements, it is recommended that the ACES model be used. This model has the capabilities to perform all calculations needed for this project including the determination of wave heights, wind set-up, wave run-up and the effects of internal structures.

The design conditions to be simulated include three (3) reservoir water depths, three (3) different combinations of rainfall and wind speeds, and two (2) different internal slope conditions. In addition, three (3) different internal breakwater structures will be simulated.

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